June 2000 Benthic Survey of

Boston Harbor Navigational Improvement

Project Confined Aquatic Disposal (CAD) Cells

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INTRODUCTION

The US Army Corps of Engineers (Corps) and the Massachusetts Port Authority (Massport) received, in 1997, the local, state, and federal permits necessary to undertake long-awaited maintenance and improvement dredging of Boston Harbor (the Boston Harbor Navigation Improvement Project or BHNIP). The project involved dredging of both channel and berth areas. Of the total 3.7 million cubic yards of material to be removed, approximately 1.3 million were unsuitable for unconfined ocean disposal. The selected disposal alternative for the unsuitable material was placement in confined aquatic disposal (CAD) cells within the Harbor as described in the Final Environmental Impact Report/Statement (June, 1995). CAD cells were to be excavated beneath existing navigation channels dredged as part of the project and capped with sand following disposal of unsuitable material into the cell.

The overall BHNIP included construction of nine CAD cells within Boston Harbor's upper tributaries (Figure 1). A limited first phase of the BHNIP was completed in the summer of 1997 and included construction, filling, and capping of a single CAD cell. The main project or second phase began in the summer of 1998 and was essentially complete by early 2000. An additional eight CAD cells were constructed during this second phase. The cells were constructed, filled, and capped over three separate intervals within the second phase of the project. The sequencing of capping of eight of the CAD cells is presented in Figure 2. The ninth cell, located in the Chelsea River, was only partially filled and remains open for use in future projects.

As part of the roll of Independent Observer for the BHNIP reporting to Massachusetts Coastal Zone Management, ENSR performed a benthic survey of selected CAD cells in June 2000 in an effort to assess re-colonization over the cells. The survey included assessment of benthic faunal composition and performance of sediment profile imaging at stations located in cells IC2, M2, M4, and M8 as well as at nearby reference areas. The following information summarizes the history of the CAD cells investigated in this survey:

IC2 - CAD cell IC2 was constructed the week of 29 June 1997. Following the completion of the cell, the unsuitable dredge material was placed in the cell from 28 June to 4 July, 1997. One week later 14 July 1997- 25 July 1997 capping operations took place to cover the contaminated sediment with a sand cap. Follow up monitoring revealed that approximately 75% of the cell received an estimated 3+ foot layer of cap material, some of which was mixed with the underlying silt material within the cell, and that 25% of the cell received little or no cap material.

M4 - Construction of CAD cell M4 took place from 10 September 1998 to 22 September 1998. Disposal of contaminated material took place from 23 September 1998 to 10 October 1998. Capping took place from 12 November to 17 November 1998. Follow up monitoring revealed that the sand cap had mixed with the cell contents over much of the cell, resulting in an estimated 6+ foot layer of sand/silt mixture.

M2 - Construction of CAD cell M2 was initiated in October of 1998. Disposal took place from October 1998 to May 1999, and capping took place in October 1999. Follow up monitoring revealed a relatively uniform layer of 2+ foot thick sand cap over much of the cell.

M8 - Construction of CAD cell M8 took place in March 1999. Disposal into the cell took place from March 1999 through January 2000. Cell M8 had not yet been capped at the time of this survey.

METHODS

Field Operations

Sampling Design and Location of Stations

Sediment samples were collected along two transects across the length and width of four CAD cells shown in Figure 1a-1c. Reference stations for biological sampling and sediment profile image photography were selected outside the navigational channel adjacent to IC2, M2, and M4. Additionally, a sediment profile image photographic reference station was selected adjacent to M8, also outside the navigational channel. Station co-ordinates are provided in Appendix A.

Eight stations were established and numbered within each CAD cell in a cross-pattern formation (Figure 3a-3c) for sediment profile image analyses. Stations within each CAD cell were located approximately 35 meters apart. A centerline across the length and width of each station was determined using a Trimble Global Positioning System (GPS) and ArcView GIS. Four stations were located along each edge and four stations were located in the middle of the individual CAD cells (Figure 3a-3c). At least three replicate sediment profile images were taken at each of the eight stations within the CAD cells. The sediment profile image photography reference stations for CAD cells M2, M4 and M8 each had three stations outside the navigational channel, CAD cell IC2 had 4 reference stations outside the navigational channel. These reference stations were located at least 50 meters away from their respective CAD cells. One replicate from each station was analyzed for the four CAD cells and their respective reference stations. This resulted in a total of 46 images analyzed for this report. Each image was scored for recent redox potential discontinuity (RPD), historical RPD's, grain size (minimum, maximum and mode), and camera penetration depth (minimum, maximum and mean). The presence or absence of burrows, infauna, successional stage, anoxia, clay clasts, methane bubbles and boundary roughness were also recorded.

Replicate benthic biology samples were taken at two separate stations within each CAD cell (stations 2 and 5, Figure 3a-3c) and a biology reference station was established approximately 50 meters away from CAD cell M4 and 80 meters away from CAD cell IC2.

Dr. Pamela Arnofsky, Mr. Don Boyé Jr., and Ms. Lori Burdick directed the field survey. CR Environmental, a small business that specializes in field support services, provided the survey vessel, the R/V *Cyprinodon* and crew. The firm of Diaz and Daughters provided the SPI camera system and a scientist, Mr. Randy Cutter, to direct the SPI field effort.

Grab Sampling

A 0.04-m² Ted Young grab was used to collect biology (benthic infaunal) samples. At each station, two grabs for benthic infauna were taken. Following collection, the benthic infaunal samples were checked for depth of the apparent RPD layer, sediment color and texture, and penetration depth of the grab, resulting in a rough estimate of the sample volume. The samples were then emptied into a bucket, sieved through 500-micron mesh screens, and fixed in 10% buffered formalin.

Sediment Profile Imaging

At each of the SPI stations, the sediment profiling camera was deployed to the seafloor (Figure 4). The camera stayed on the bottom for 20 sec (measured with a stop watch on board ship starting at the point at which the wire went slack). Two photographs were taken with each deployment: the first one was taken 5 sec after the frame settled on the bottom and the second one, 15 sec later.

This protocol assures that at least one useable photograph is produced during each lowering. If the bottom is very soft, the prism will over penetrate after 15 sec (no sediment-water interface on the photograph), but the first exposure, taken after 5 sec, usually shows the interface and will be suitable for a

full analysis. If the sediment is compacted or mixed with rocks, the second exposure will be used for analysis. At least three replicate sets (six exposures) were taken at each of the 35 stations. At the end of each station, the camera was hauled back on deck for transport to the next station.

Sections of the film were cut and developed at the end of the day to ensure that the camera system was working correctly. The remaining film was developed by the MicroGraphics Laboratory, Woods Hole Oceanographic Institution. Mounted slides were later sent to a Kodak Laboratory for digitizing and archival on a CD-ROM. These digitized images were then analyzed in the laboratory**.**

Sediment Grain-Size Analysis

Grain size was determined by a combination of wet and dry sieve and pipette analysis. The sediment was processed through a sieve series based on the Wentworth grade scale, including mesh sizes of 2 mm (-1 phi), 1 mm (0 phi), 0.5 mm (1 phi), 0.25 mm (2 phi), 0.125 mm (3 phi), and 0.063 mm (4 phi). The sediment fraction retained on each sieve was weighed and reported as percent gravel (grain size >2 mm) and percent sand (grain size 2 mm to 0.063 mm). Sediment passing through the 0.063-mm sieve was further analyzed by pipette analysis to obtain percent silt (grain size 0.063 mm to 0.004 mm) and percent clay (grain size <0.004 mm). For the sand fraction, the weight percent for each phi size was also determined.

Sample Documentation, Custody, and Quality Assurance/Quality Control

Standard ENSR procedures for sample tracking and custody were followed. Prior to the survey, preprinted labels were produced. All sample containers were labeled on the outside, and the infauna containers were also labeled on the inside. Information on the labels included the survey number, date and time of sampling, station and replicate, sample type, and the laboratory to which the samples were to be delivered for analysis.

All pertinent information on field activities and sampling efforts was recorded into a bound, numbered logbook. Entries were recorded in indelible ink and included, at a minimum,

- Date and time of starting work
- Names of ship's crew and scientific party
- Sampling sites and activities and references to ship's navigation system
- Deviations from survey plan, if any
- Field observations such as weather and sea state

Chain-of-custody forms were created by hand before the samples left the survey vessel or the custody of the scientist responsible for shipping. All coolers and boxes used for shipping were sealed with numbered chain-of-custody tape; the number on the tape was recorded on the chain-of-custody form. For additional information, ENSR has prepared a Quality Assurance Project Plan (QAPP) for Benthic Monitoring (Blake and Hilbig, 1995).

Laboratory Methods: Sample Processing and Analysis

Benthic Infauna

In the laboratory, each benthic sample was resieved with fresh water through a 500-micron mesh screen and transferred to 70% alcohol for preservation. Before sorting, the samples were stained with a saturated alcoholic solution of Rose Bengal, a stain for proteins that enhances the visibility of organisms in the sediment. All animals, including anterior fragments, were removed from the sediment and sorted into major taxa, such as polychaetes, oligochaetes, mollusks, crustaceans, and echinoderms. Taxonomists then

identified each taxon to the lowest practical level (usually to species) and enumerated each taxon. Sorting and identification of the benthic infauna was performed by ENSR taxonomists. A detailed description of the procedure can be found in the QAPP for Benthic Monitoring (Blake and Hilbig, 1995). Replicate 1 from each station was analyzed; the second replicate from each station was archived at ENSR after transfer to ethanol.

Sediment Profile Image (SPI) Analysis

One out of three replicate images from each station were analyzed with ImagePro Plus software in the ENSR Marine & Coastal Center's image analysis laboratory in Woods Hole. Each digitized image was analyzed for penetration depth, surface roughness, apparent redox potential discontinuity (RPD), grain size major mode, successional stage of the infauna, the presence of methane bubbles, and biogenic features such as burrows and tubes. Any additional observations were entered into a comment field. The data were compiled on separate data sheets for each image and the organism-sediment index (OSI) was calculated (Rhoads and Germano, 1982).

The following is a description of each of the SPI parameters that were measured:

1. *Penetration depth* is measured from the bottom of the image to the sediment-water interface (maximally 20 cm) and is a measure for softness of the substratum, which depends on characteristics such as water content and grain size.

2. *Surface roughness* is the difference between the least and greatest penetration depth across the sediment-water interface depicted on a slide (the width is 15 cm). It may be a measure for physical disturbance—natural or anthropogenic—or biological activity such as burrowing.

3. The *apparent RPD depth* is measured from the sediment-water interface to the depth in the sediment at which there is a change in sediment color caused by the lack or absence of oxygen at depth; the color commonly changes from tan or brownish (ferric hydroxides) in the well-oxygenated surface layer to greyish (ferric hydroxides being reduced) or black (presence of sulfide, anoxic conditions) at a few mm to several cm depth. The RPD depth depends on a variety of physical and biological factors, such as currents, organic loading, and bioturbation by infaunal organisms, and is commonly used as a first-approximation measure for the health of a habitat.

4. *Methane bubbles*, discernable by their strong reflectance (silvery color), form only under severely oxygen-depleted sediment conditions as a result of anaerobic bacterial metabolism.

5. The *grain size major mode* is the dominant particle size in an image, measured visually by comparing the slide with a photograph of phi size classes.

6. The *infaunal successional stages* are derived from a paradigm describing recolonization of disturbed habitats. Stage I organisms are those that live very close to the sediment-water interface, and they are pioneers because they do not require much oxidized sediment. By their feeding and burrowing activities these stage I organisms, often small annelids, deepen the RPD, preparing the sediment for somewhat larger animals to colonize, such as certain amphipods (stage II). Stage III organisms are large, deep-burrowing, head-down deposit feeders, such as large polychaetes and echinoderms, that aerate the sediment to several cm depth. Their presence indicates an equilibrium community and healthy environment.

Data Management and Analysis

Benthic Infauna

Data from infaunal identifications were either entered directly into a Microsoft Excel spreadsheet or documented manually on data sheets and then entered into a spreadsheet. Juvenile and indeterminable organisms were included in calculations of density. Data analysis included species richness as well as an assessment of faunal assemblages. Diversity was calculated as the Shannon-Wiener index (H') and Pileou's evenness (J'). The Shannon-Wiener index was calculated using the base $\log_e$.

Sediment Profile Image Analysis

A spreadsheet of the raw data was generated and several parameters mapped and contoured. Major modal grain size designations plotted for each station represent the dominant modal sediment type among the station replicates. The mean apparent RPD depth (rounded up to the first two decimal places) is plotted along with presence/absence of microbial mats, methane gas, dewatering pipes, and oxic/anoxic surfaces. Total number of relic and recent RPDs are also plotted. The successional status of each station is plotted as the dominant sere as inferred from the replicates. The OSI values that are plotted are the stations means rounded up to a whole number.

RESULTS

Sediment Grain Size

Grain-size composition of sediments collected in June 2000 from the biology grabs collected at two stations in each of the CAD cells and at the references sites, as determined by sieving and gravimetric analysis, is given in Table 1. Inspection of the data shows that the majority of stations are characterized by fine-grained sediments typically found in anthropogenically affected areas of Boston Inner Harbor. Sediment grain size distribution associated with each biology station is plotted for each station in Figure 3.

One station in CAD cell M8 (M8-B-1B) and one in CAD cell M4 (M4-2-1A) had >40% but <50%of very fine sand. The remaining stations were predominantly comprised of fine-grained sediments with varying percentages of silt and clay. Station M2-B-1a had highest percentage of clay (47%) and station M8-B-2A rep. 3 had highest percentage of silt (67.3%). The remaining stations had silt+clay values ranging from 69.1% to 95.1% (Table 1).

Benthos

The benthic samples taken from the four CAD cells and the reference sites for the BHNIP project in June 2000 yielded no particularly rare or unusual organisms. Some samples contained plant material (e.g., M2, M4 and M8). *Capitella capitata* was the only species found at each of the CAD cells and at the reference stations. *Polydora cornuta* was found at every station in the four CAD cells except M2-B-1A and *Streblospio benedicti* was found at all stations in the four CAD cells except M2-B-1A and M2-B-2A. IC2 had the greatest abundance of Capitella capitata.

Taxonomic Composition

A total of 22 taxa were identified from the benthic samples (Appendix B-1 and B-2). Polychaete annelids accounted for 11 taxa (50%) and all were identified to species. Two species of gastropods were identified from shells only, no live gastropods were found in any of the biology samples. Four species of bivalve molluscs were recorded all identified to species. Crustaceans were represented by one species of amphipod and one species of decapod. The remaining taxa included one species of hydroid and two species of oligochaete annelids.

Distribution and Density of Dominant Species

Appendix B-2 includes the counts of each taxon recorded at each of the 10 stations sampled. Table 2 provides a list of the taxa recorded, along with the percentage contributed by each major taxonomic group and the number of stations at which each occurred.

Table 1. Grain-size analysis of sediments from stations sampled in June 2000 from four CAD cells and reference stations taken from benthic faunal grabs.

Sample	%	%	%	%	%	PHI PERCENT					Mean	Std
	Gravel	Sand	Silt	Clay	Silt + Clay	<-1	0	1	2	3	4		Dev
M2-B-1A	0	15.4	37.2	47.4	84.6	0	0.08	0.34	1.35	2.37	11.24	6.97	2.17
M4-5B	0	15.2	58.2	26.6	84.8	0	2.35	0.65	1.29	4.69	6.22	6.23	2.18
IC2BRA	0	16.2	48.6	35.2	83.8	0	0.28	1.75	3.55	3.33	7.33	6.48	2.27
IC-B4-1A	0	16.2	57	26.9	83.9	0	0.12	0.35	1.67	3.23	10.8	6.32	1.97
M8-B-1B	0	40.1	38.6	21.3	59.9	0	1.41	1.5	19.22	10.69	7.31	5.04	2.78
IC2-B-2A	0	23.9	45.5	30.6	76.1	0	0.06	0.88	3.64	6.9	12.42	6.15	2.32
M2-4-REF	0	21	55.8	23.2	79	0	0.1	0.45	7.03	6.83	6.63	5.94	2.22
M4-2-1A	0.2	46.9	30.3	22.6	52.9	0.16	0.56	10.19	22.89	8.88	4.42	4.62	3.09
M2-B-2A	3.8	27.1	32.5	36.6	69.1	3.78	2.95	5.14	7.71	5.9	5.37	5.65	3.27
M8-B-2A(A)	0	5.4	63	31.6	94.6	0	0	0.07	0.49	1.19	3.65	6.79	1.65
M8-B-2A(B)	0	4.9	62.9	32.2	95.1	0	0	0.07	0.4	1.21	3.24	6.82	1.64
M8-B-2A(C)	0	6.5	67.3	26.3	93.6	0	0.07	0.14	0.63	1.39	4.24	6.59	1.63

The numerically dominant species were not evenly distributed among the 10 stations. Polychaetes contributed the majority of species and the majority of individuals. However, *Capitella capitata* was only numerically dominant in CAD cells IC2-B-1A, M2-B-2A, M4-5A, and M8-B-2A. *Polydora cornuta* was numerically dominant at the reference station (IC2-B-RA), M4-2A, and M8-B-1A 4. The remaining stations had equivalent numbers of *Capitella capitata* and *Polydora cornuta* except station IC2-B-2A. This station was numerically dominated by *Tubificoides apectinatus*, an oligochaete worm and M2-B-1A had only 4 animals identified from the entire sample. These four animals were comprised of three tiny *Mytilus edulis* and one *Capitella capitata*. Reasons for such low numbers of individuals and species at M2-B-1A could be related to a recent slumping event from the CAD cell walls that would smother previously existing, living animals or anthropogenic disturbance. *Capitella capitata*, *Polydora cornuta*, and *Tubificoides apectinatus* are Stage I species that opportunistically enter open niche space (Rhoads and Germano, 1982). Mollusks, gastropods, and crusteacans were not numerically abundant at any of the 10 benthic faunal stations.

Table 2. Species identified from BHNIP CAD cell stations, their distribution and relative occurrence.

Taxon	No. of Individuals	Percent Total	No. of Stations	Percent of Stations	Cumulative percent by major taxonomic group
Capitella capitata complex	165	29.6	10	100	33.13
Polydora cornuta	149	26.8	9	90	29.92
Tubificoides apectinatus	74	13.3	8	80	66.07
Streblospio benedicti	42	7.5	8	80	8.43
Tubificoides sp. 2	38	6.8	7	70	33.93
Tharyx acutus	30	5.4	5	50	6.02
Micropthalmus sczelkowii	14	2.5	2	20	2.81
Mytilus edulis	13	2.3	5	50	72.22
Mediomastus ambiseta	8	1.4	2	20	1.60
Spio thulini	6	1.1	3	30	1.20
Nephtys incisa	5	0.9	3	30	1.00
Trochochaeta multisetosa	3	0.5	3	30	0.60
Tellina agilis	3	0.5	3	30	16.67
Ampelisca abdita	2	0.4	1	10	66.67
Yoldia limatula	1	0.2	1	10	5.56
Nereis grayi	1	0.2	1	10	0.20
Mya arenaria	1	0.2	1	10	5.56
Glycera americana	1	0.2	1	10	0.20
Crangon septemspinosa	1	0.2	1	10	33.33
Lacuna vincta	N/A	N/A	N/A	N/A	N/A
Ilyanassa trivittata	N/A	N/A	N/A	N/A	N/A
Campanularia gigantea	N/A	N/A	N/A	N/A	N/A

N/A= Not Applicable

Species Richness and Diversity

Community parameters for each station are given in Table 3. Species diversity, as measured by the Shannon index H′, ranged from a low of 0.22 at Station M2-B-1A to a high of 1.92 at Station IC2-B-2A. Species richness (total number of taxa) and diversity were highest at CAD Cell IC2 and M8. Cell IC2 was the first to be constructed, filled and capped and therefore has had the greatest amount of settling time in the history of the BHNIP. CAD cell M8 has been constructed and filled with dredged sediment, but no coarse sand cap has been placed at the time of this study. All the cells are subject to natural filling from ambient sediment existing along the edges of the dredged cell. In addition, because the cells are depressed below the surrounding harbor bottom, the edges can potentially slump in over the cell contents and act as an ambient cap. As evidenced by the sediment profile imagery, diversity and species richness results, the natural benthic fauna are re-establishing themselves at the surface of the cells.

CAD cell M2 was reported to have the most evenly distributed sand cap but also had the lowest diversity and species richness of all 4 CAD cells investigated. This could result from recent depositional events that take place as the cell walls slump into the cell thus creating temporary anoxic environments. Cell M4 that was reported to have the most uneven distribution of sand cap material, and the reference station IC2-B-RA, both have diversity and species richness similar to that of IC2 and M8. The sediment profile image photography results of all stations within these 4 CAD cells show clear evidence of multiple resuspension events and potential slumping from the cell wall edges. This, in turn, supports the hypothesis that low diversity at cell M2 can be related to the recent slumping events and temporary anoxic environment created by this circumstance. It is also important to note that diversity is not exceptionally high at any of the BHNIP stations, but it is comparable to other areas with equal levels of disturbance and contamination such as western Long Island Sound and Inner Boston Harbor (ENSR, 2000; Blake et al., 1998).

Table 3. Community parameters from stations sampled within the BHNIP CAD cells.

Station	Number of Individuals	Number of Taxa	H'	J'
IC2-B-1A	96	10	1.58	0.68
IC2-B-2A	144	12	1.92	0.77
IC2-B-RA	100	9	1.14	0.52
M2-4	26	6	1.38	0.77
M2-B-1A	4	2	0.22	0.31
M2-B-2A	28	6	0.76	0.42
M4-2A	63	8	1.50	0.77
M4-5A	35	8	1.77	0.91
M8-B-1A	16	10	1.84	0.88
M8-B-2A	45	7	1.43	0.74
Total	557	22		

Sediment Profile Camera Imaging

Appendix C includes detailed information from the analysis of the images taken with the SPI camera. The plates referred to in the following section are presented in Appendix D.

Distribution of Sediment Types

Figure 6a-6d show the distribution of major modal grain size and number of relic and recent RPD layers at each station as inferred from image analysis of the SPI data. Most stations (> 70%) consist of predominantly silt-clay mud with varying proportions of very fine sand and coarse sand cap material.

Coarse sand is labeled CS, silt is labeled as Si, clay is labeled as C, and very fine sand is labeled VFS for all stations in each of the CAD cells and reference stations. CAD cell M2 has coarse sand cap material at all stations except 7 (Figure 6a). The major modal grain size at cell M2 is >4.0) phi indicating that silt dominates this cell and there was little very fine sand present. There were no samples taken from within the coarser sand cap material and the grain size data represents material taken from the top 15 cm. The three reference stations for cell M2 consisted of silt over clay with a minimal amount of very fine sand mixed throughout.

CAD cell M4 has coarse sand cap material present at all stations except station 4 (Figure 6b). This cell has a greater amount of very fine sand present at the surface when compared to CAD cell M2. The major

modal grain size at cell M4 is less than 4.0 but greater than 3.0 . The three reference stations for cell M4 were comprised of silt over clay with a major modal grain size >4.0 phi. No sand was present at these reference stations (Figure 6b).

CAD cell IC2 consists of predominantly silt over clay. Stations 1, 2, and 3 at cell IC2 had minimal amounts of very fine sand mixed with silt at the surface. The remaining five stations were all comprised of silt over clay. The major modal grain size for this cell was >4.0. The four reference stations for IC2 were comprised of all silt over clay. No coarse sand cap material was visible within the view of the sediment profile image photographic prism (Figure 6c).

CAD cell M8 had very fine sand mixed with silt at the surface for all stations. Below this layer was silt and the major modal grain size was >4.0 and since this cell remains uncapped there was no evidence of and coarse sand cap material. Reference stations EX1,2, and 3 were each comprised of silt/clay. (Figure 6d)

There is evidence of relic RPD's at every station in each of the CAD cells. Some relic layers are quite large and indicate quantum input (large quantities of sediment deposited in a single event) of material potentially caused from slumping events at the cell's edge. There is also evidence for recent sediment depositional intervals (RSDIs). This is most likely caused by anthropogenic disturbance such as propeller thrusting and shipping vessel activity. These RSDI events are much thinner than the slumping quantum events and can be seen close to the surface (Plate 1, Appendix D).

Mean Apparent RPD Depths

Figure 7a-7d show the distribution of the recent mean apparent RPD depths over the surveyed area in each of the four CAD cells and reference stations. These figures also map the presence or absence of dewatering pipes, methane bubbles, and anoxic (no oxygen at the sediment-water interface) surfaces. The recent apparent RPD depths (in cm) distinguish between the intensively mixed surface zone and the anoxic zone that lies beneath. Mixing processes include bioturbation, predator foraging, and water turbulence (resuspension and transport). Dewatering pipes are evidence of sediment compaction that forces interstitial water toward the surface (Plate 2, Appendix D). CAD cell IC2 (Figure 7c) had the deepest recent apparent RPD depths. The greatest recent RPD depth at IC2 was 1.08 cm. This CAD cell had the greatest abundance of benthic fauna, when compared to other CAD cells, and thus the deeper recent RPD depths may be attributed to bioturbation (Table 3).

The remaining cells did not have recent RPD depth greater than 1.0 cm. CAD cell M8 (Figure 5D), which was most recently dredged and filled but not capped, had recent RPD values ranging between 0.38cm to 0.93cm. CAD cell M4 (Figure 7b) that had the most uneven distribution of cap material over the contaminated sediment had recent RPD depth values ranging between 0.27cm and 0.66cm. CAD cell M2 (Figure 7a) had only oxic surfaces at stations 1 and 2 with

shallow recent RPD depths of 0.24cm and 0.40cm, respectively. Stations 2,3,4,5,7,and 8 all had anoxic surfaces and this may be attributed to recent quantum input of edge material overlaying the capped toxic sediment caused by the slumping of the CAD cell walls.

Overall, the aggregate recent RPD depths are shallow in all the CAD cells, likely due to cell edge slumping and redepositional disturbance events caused by anthropogenic uses of the shipping channel (Plate 3, Appendix D).

Benthic Processes

Figure 7a-7d show the presence of methane gas as imaged in sediment profile photographs. Also included on these figures are apparent anoxic/oxic conditions at the sediment-water interface as inferred

from the presence/absence of low-reflectance sulfidic sediment, RPD depth and the presence/absence of dewatering pipes. All stations at each of the CAD cells and reference stations showed physical disturbance. Physical bottom disturbance can be caused by turbulent resuspension from currents, prop wash, bow-wave wash, bottom scouring, or foraging activities of demersal fish and crustaceans. Any activity associated with dredging, disposal of material and erosion of cell edges would cause physical disturbance of the bottom.

The quality of the over-lying water column and sediment itself impacts benthic community structure. Areas that experience high rates of nitrogen loading (eutrophication) and presence of organic toxic chemicals tend to generate sediment inventories of methane gas by promoting the growth of bacteria that reduce dissolved oxygen in the water column. As the bacteria thrive and create an anoxic environment, the benthic faunal diversity (which depends on oxygenated sediment-water interface) decreases. Certain anaerobic bacteria species are able to fix excess carbon to produce methane gas while others have the ability to fix excess sulfur and produce hydrogen sulfide gas. When the inventory of methane gas is large, sediment profile images show the presence of gas bubbles within the sediment column. Three stations at cell M2 (2, 7, and 8) and two stations at M4 (2 and 7) show the presence of methane gas bubbles below the sediment surface (Plate 4, Appendix D). When oxygen concentrations are low, sediment profile images show a very thin apparent RPD (or no RPD) and low-reflectance sulfidic microbial mat at the sediment-water interface (Plate 5, Appendix D). Fourteen of the 45 stations had a recent RPD depth of 0.40 cm or less which suggests that approximately 30% of the surveyed stations demonstrate sediments with very shallow oxidation. 100% of these stations including the reference sites are physically disturbed.

Successional Status

The successional status of each CAD cell station is shown in Figure 8a-8d along with the presence or absence of microbial mats of sulfur reducing bacteria. These microbial mats are present when the sediment-water interface is anoxic (Plate 5, Appendix D). CAD cell M4, M2 and M8 (Figures 8a, 8b, and 8d) are dominated by Stage I organisms that include polychaetes (*Capitella capitata*, *Polydora cornuta,* and *Streblospio benedicti*), and oligochaetes (*Tubificoides apectinatus*). CAD cell IC2 (Figure 8c) was also dominated by Stage I organisms but also had Stage II and III organisms present in very low numbers. These Stage II and III organisms found at IC2 were: one amphipod (*Ampelisca abdita*), one decapod (*Crangon septimspinosa*), and one polychaete (*Nephtys incisa*). Two opportunistic species of bivalves (*Tellina agilis* and *Yoldia limatula*) were also found at CAD cell IC2 and the reference station IC2-R but were not present at any other cell or reference station. This is typical for benthic habitats that are recently and/or consistently disturbed.

Organism-Sediment Indices

Spatial trends in the organism-sediment indices (OSI) are shown in Figures 9a-9d along with the number of relic RPDs found at each station. The lowest indices (negative) are found at CAD cell M2 at stations 2 (-10), 3 (-3), 4 (-8), 5 (-3), 7 (-10), and 8. All of these stations show evidence of no dissolved oxygen near the sediment-water interface (see Figure 9A). Experience with mapping OSI values has shown that OSI values of less than +6 represent physically disturbed or otherwise degraded benthic habitats. Using this threshold OSI criterion, 100% of the stations sampled in June 2000 represent physically disturbed or degraded conditions. This is to be expected as these CAD cells were recently constructed, filled and in some cases capped. All reference stations for each of the CAD cells had OSI values of either +1 or +2. There were oxic surfaces at each of these stations but these values suggest that even the reference stations are quite disturbed. Bottom scouring from marine vessel traffic is most likely the cause of this disturbance. One reference station at IC2 (IC2-R-2) had a value of +6 which suggests that IC2-R-2 is marginally less disturbed when compared to the other stations.

Discussion

This survey of the 4 CAD cells and their associated reference sites shows that bottom 20 cm of sediment located both inside and outside the cells are predominantly comprised of silt. The presence of dewatering pipes within CAD cell M8 is evidence that the dredged disposal material is settling and forcing trapped water toward the surface of the cell. Both CAD cell M4 and M8 had a thin layer of very fine sand at the surface, cells M2 and IC2 had silt at the surface. OSI values suggest that the CAD cell benthic surfaces and the reference sites are both disturbed. The low biodiversity values at both the cell stations and reference stations also suggest that the benthic environment over the entire in-channel area is consistently subjected to disturbance. Thus, impact to the benthic habitat caused by dredging, filling, and capping these cells is far less than if this area was completely undisturbed with naturally high biodiversity.

Mean recent apparent RPD depths are equal to, or less than, 2.44 cm deep. The majority of stations have mean recent apparent RPD depths 0.30-0.75 cm. Most RPD depths (98%) are less than 2 cm deep and half (92%) are less than 1 cm deep. The thin depth of the RPD is attributed to the shallow bioturbation associated with Stage I species (see below), and the apparent high sediment oxygen demand of the organic mud fraction of these sediments.

Most (> 90%) of the stations are dominated by Stage I seres (a sere is the successional stage of a habitat) or are apparently azoic with respect to macrofauna (M2-2-3-1, M2-4-4-1, and M2-7-2-2). Stage I seres are dominated by the opportunistic polychaetes and oligochaetes (*Capitella capitata*, *Polydora cornuta*, *Tubificoides apectinaria*). These assemblages are apparently productive but have low biodiversity. Only at IC2 were Stage II seres found with the appearance of an amphipod and decapod.

Because most stations have thin apparent RPDs, low successional status, and some stations show the presence of methane and low dissolved oxygen at the sediment-water interface, the resulting OSI values for the surveyed stations are low compared outer Boston Harbor habitats. Only one station has an OSI value equal to +6. By comparison, stations sampled for the Boston Harbor Soft Bottom Benthic Monitoring Program (1996-1997) for MWRA showed that >80% of stations in outer Boston Harbor were >+6. Stations in the lower Charles River, for this MWRA survey, ranged between +4 to +7.3 (Blake et al. 1998). The majority of stations in the CAD cells and reference stations for the BHNIP June 2000 survey had OSI values of +2, much lower than any of the MWRA stations suggesting that the Inner Confluence/Mystic River area is more disturbed than the lower Charles River or outer Boston Harbor. The BHNIP stations had values similar to Dorchester and Hingham Bays, highly eutrophic and disturbed habitats.

Factors that may be operating to produce degraded benthic habitats along the surveyed route include (but are not limited to) physical bottom instability, and other mechanisms that can suspend sediment or otherwise erode the bottom (e.g., prop wash, bow waves, bottom foraging). High rates of organic loading are also apparently degrading the benthic habitats as manifested in images of sediment methane gas and sulfidic sediment at the sediment-water interface.

The impact of excavating, filling, and capping the cells for the BHNIP adds a level of local disturbance that is likely only slightly greater than the dredging that was performed in the area. However, this system is generally already experiencing high levels of ambient chemical and physical disturbance. Based on the results of this survey and because the ambient biological community is already adapted to disturbance, the recovery of the benthic habitat in the CAD cells is quite rapid, and recolonization can take place within days as evidenced by the multiple redepositional layers and presence of bioturbation in the sediment profile imagery.

REFERENCES CITED

Blake, J.A. and B. Hilbig. 1995. Combined Work/Quality Assurance Program Plan (CW/QAPP) for Benthic Monitoring: 1995-1997. MWRA Environmental Quality Department Misc. Rpt. No. MS-34. Massachusetts Water Resources Authority, Boston, MA. 68 pp.

Blake, J.A., I.P. Williams, E.D. Gallagher, B. Hecker, D.C. Rhoads, and P.L. Arnofsky. 1998. Massachusetts Bay Outfall Monitoring Program: Benthic Biology and Sedimentology Baseline Monitoring for 1997 and Retrospective Analysis of the 1992-1997 Database. Massachusetts Water Resources Authority, Environmental Quality Department, Technical Report Series No. 98-16. 153 pp. + 8 Appendices.

ENSR. 1997. Summary report of independent observations Phase I-Boston Harbor Navigation Improvement Project. Prepared for Massachusetts Coastal Zone Management. ENSR. Document Number 4479-001-150, ENSR, Acton, MA.

ENSR. 2000. Application of Iroquois Gas Transmission System, L.P. for a Certificate of Public Convenience and Necessity. Volume II. Environmental Resource Reports. 200 pp. Volume III. Biological Assessment. 135 pp. plus Appendices A–E.

Rhoads, D.C. and J.D. Germano. 1982. Characterization of organism-sediment relations using sediment profile imaging: An efficient method of Remote Ecological Monitoring of the Seafloor (REMOTS® system). *Marine Ecology Progress Series* 8: 115-128.

ALL FIGURES NOT INCLUDED; CONTACT CZM FOR HARD COPY OF REPORT.

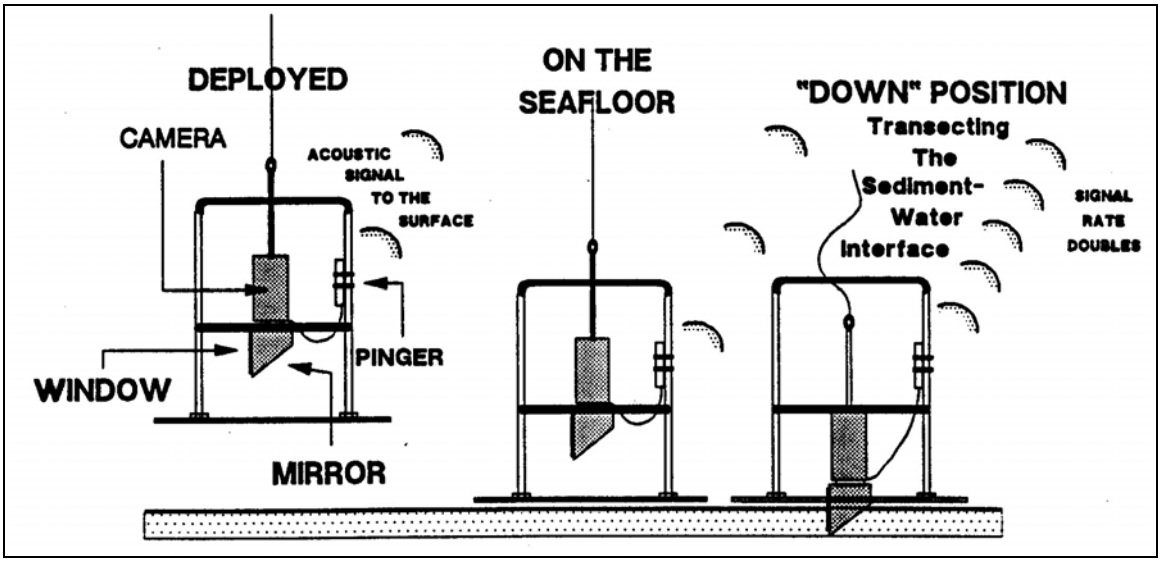
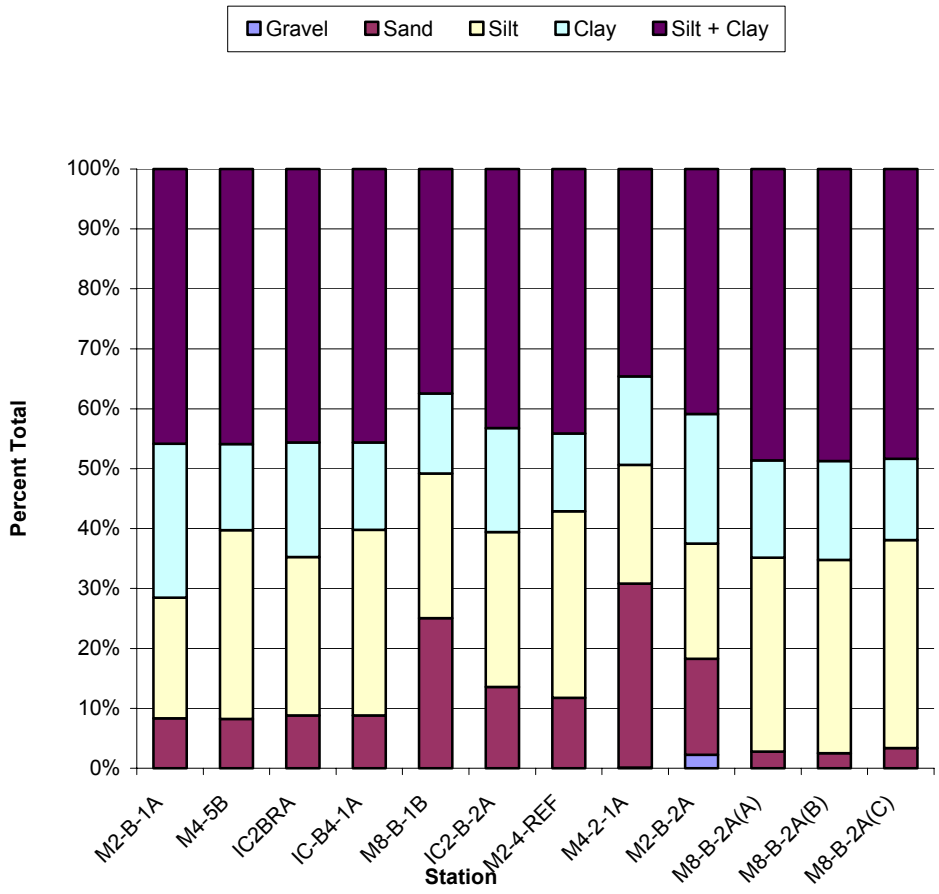


Figure 4. Diagram of the Benthos Model 3731 sediment profile camera in operational mode

Figure 5. Grain Size Distribution at Biology CAD Cell Stations.



Appendix A. Station Co-ordinates for Analyzed Biology and Sediment Profile Image Photography Stations

COORDINATES FOR BIOLOGY SAMPLES COLLECTED IN JUNE 2000			
Station	**Latitude (N)**	**Longitude (W)**	**Depth (ft)**
IC2-B-1A	42.37862747	-71.04425922	54
IC2-B-2A	42.37947806	-71.04422916	50
IC2-B-RA	42.37849277	-71.04591025	46
M2-4	**9046220 N**	**235808.5 E**	**36**
M2B-1A	42.38787515	-71.06684355	55
M2-B-2A	42.38771944	-71.06580408	54
M4-2A	42.38767020	-71.06475624	43
M4-5A	42.38753603	-71.06375064	52
M8-B-1A	42.38617318	-71.05893384	58
M8-B-2A	42.38604286	-71.05727878	54

COORDINATES FOR SPI CAMERA STATIONS FOR THE BHNIP JUNE 2000 SURVEY				
Station	**Rep**	**Latitude (N)**	**Longitude (W)**	**Depth (ft)**
IC2	1-1	42.37873332	-71.04426999	50
	1-2	42.37875191	-71.04425747	50
	1-3	42.37885241	-71.04417236	50
IC2	2-1	42.37865384	-71.04443255	55
	2-2	42.37864745	-71.04418173	55
	2-3	42.37869785	-71.04411082	55
IC2	3-1	42.37904518	-71.04422257	53
	3-2	42.37893393	-71.04416181	53
	3-3	42.37891555	-71.04422594	55
IC2	4-1	42.37919533	-71.0441286	53
	4-1	42.37927268	-71.04415415	54
	4-3	42.37926214	-71.04403923	54
	4-4	42.37948053	-71.04389765	54
IC2	5-1	42.37943769	-71.04419801	55
	5-2	42.37948862	-71.04405484	55
	5-3	42.37948183	-71.04422732	55
IC2	6-1	42.37969370	-71.04427934	55
	6-2	42.37967835	-71.04415390	55
	6-3	42.37979020	-71.04416402	55
IC2	7-1	42.37898368	-71.04390354	54
	7-2	42.37897270	-71.04385954	54
	7-3	42.37889909	-71.04389055	56
	7-4	42.37894121	-71.04379602	56
IC2	8-1	42.37897046	-71.04440623	55
	8-2	42.37898550	-71.04434079	56
	8-3	42.37893570	-71.04426720	56

COORDINATES FOR SPI CAMERA STATIONS FOR THE BHNIP JUNE 2000 SURVEY				
Station	**Rep**	**Latitude (N)**	**Longitude (W)**	**Depth (ft)**
M8	1-1	42.38629566	-71.05929561	63
	1-2	42.38625037	-71.05924832	62
	1-3	42.38649058	-71.05892398	61
	1-4	42.38627618	-71.05919313	61
	1-5	42.38648008	-71.05907136	63
M8	2-1	42.38633716	-71.05877871	62
	2-2	42.38634326	-71.05874977	62
	2-3	42.38613411	-71.05883939	61
	2-4	42.38610023	-71.05871612	61
M8	3-1	42.38602797	-71.05830033	63
	3-2	42.38615475	-71.05828244	63
	3-3	42.38620623	-71.05802037	63
	3-4	42.38619826	-71.05810107	63
	3-5	42.38610842	-71.0584795	63
M8	4-1	42.38613762	-71.05771434	63
	4-1	42.38609791	-71.05782828	63
	4-3	42.38619958	-71.05781373	63
M8	5-1	42.38607119	-71.05717888	63
	5-2	42.38592715	-71.05727291	63
	5-3	42.38605518	-71.05713685	63
M8	6-1	42.38602068	-71.05671072	56
	6-2	42.38602271	-71.05669965	52
	6-3	42.38584018	-71.05675946	53
M8	7-1	42.38634365	-71.05821809	59
	7-2	42.3863386	-71.05819238	59
	7-3	42.3865468	-71.0583709	48
	7-4	42.3864107	-71.05825806	56
	7-5	42.38629252	-71.05824262	59
M8	8-1	42.38611049	-71.05829234	58
	8-2	42.3861166	-71.05826534	59
	8-3	42.38607972	-71.05815764	59

COORDINATES FOR SPI CAMERA STATIONS FOR THE BHNIP JUNE 2000 SURVEY				
Station	**Rep**	**Latitude (N)**	**Longitude (W)**	**Depth (ft)**
M4	1-1	42.38763746	-71.06485921	50
	1-2	42.38770329	-71.06488936	55
	1-3	42.38769683	-71.06486973	55
M4	2-1	42.38760940	-71.06486571	54
	2-2	42.38756177	-71.06484163	45
	2-3	42.38762929	-71.06462743	45
	2-4	42.38764669	-71.06463362	58
	2-5	42.38768743	-71.06469455	58
M4	3-1	42.38758373	-71.06438910	57
	3-2	42.38763053	-71.06440833	57
	3-3	42.38763358	-71.06438123	57
M4	4-1	42.38758071	-71.06413761	57
	4-1	42.38753930	-71.06406795	53
	4-3	42.38755263	-71.06423448	49
M4	5-1	42.38754768	-71.06380642	58
	5-2	42.38753808	-71.06374467	58
	5-3	42.38748696	-71.06374903	59
M4	6-1	42.38754197	-71.06348937	60
	6-2	42.38748842	-71.06354038	60
	6-3	42.38747124	-71.06356952	60
	6-4	42.38742076	-71.06357497	48
	6-5	42.38749007	-71.06350211	48
M4	7-1	42.38773441	-71.06440361	58
	7-2	42.38774263	-71.06417451	58
	7-3	42.38764856	-71.06434251	58
	7-4	42.38771359	-71.06442197	58
	7-5	42.38764350	-71.06433793	58
M4	8-1	42.38755144	-71.06444397	52
	8-2	42.38751731	-71.06427370	52
	8-3	42.38749675	-71.06440889	52
	8-4	42.38762066	-71.06456008	52

COORDINATES FOR SPI CAMERA STATIONS FOR THE BHNIP JUNE 2000 SURVEY				
Station	**Rep**	**Latitude (N)**	**Longitude (W)**	**Depth (ft)**
M2	1-1	42.38784513	-71.06680854	57
	1-2	42.38793469	-71.06685092	57
	1-3	42.38792470	-71.06678018	57
	1-4	42.38798088	-71.06685364	57
M2	2-1	42.38787901	-71.06672135	61
	2-2	42.38767213	-71.06653198	61
	2-3	42.38783615	-71.06667197	61
M2	3-1	42.38783390	-71.06631336	60
	3-2	42.38780366	-71.06631515	60
	3-3	42.38782125	-71.06639555	60
	3-4	42.38784965	-71.06635941	61
	3-5	42.38784058	-71.06641266	61
M2	4-1	42.38776886	-71.06608756	59
	4-1	42.38777407	-71.06608461	59
	4-3	42.38777760	-71.06609029	60
	4-4	42.38779231	-71.06607416	59
M2	5-1	42.38769238	-71.06574197	63
	5-2	42.38776358	-71.06576128	62
	5-3	42.38776359	-71.06574148	63
M2	6-1	42.38766371	-71.06542216	63
	6-2	42.38771404	-71.06535113	63
	6-3	42.38768494	-71.06541521	63
	6-4	42.38770604	-71.06542491	63
M2	7-1	42.38800909	-71.06633682	60
	7-2	42.38796956	-71.06638117	60
	7-3	42.38803283	-71.06632925	61
	7-4	42.38796250	-71.06629912	60
M2	8-1	42.38776599	-71.06649575	61
	8-2	42.38774341	-71.06638114	61
	8-3	42.38774685	-71.06638695	61
	8-4	42.38775276	-71.06647374	61

COORDINATES FOR REFERENCE SPI CAMERA STATIONS FOR THE BHNIP JUNE 2000 SURVEY				
Station	**Rep**	**Latitude (N)**	**Longitude (W)**	**Depth (ft)**
M4-R	1-1	42.38710810	-71.06512371	43
	1-2	42.38708856	-71.06507381	43
	1-3	42.38673276	-71.06509581	43
M4-S	2-1	42.38654124	-71.06401775	43
	2-2	42.38654092	-71.06398217	43
	2-3	42.38653520	-71.06396921	43
M4-T	3-1	42.38645764	-71.06329295	43
	3-2	42.38645597	-71.06325374	43
	3-3	42.38642888	-71.06316357	43
M2-R	4-1	42.38678825	-71.06593945	38
	4-1	42.38687188	-71.06603409	38
	4-3	42.38687572	-71.06609636	38
EX	1	42.38761073	-71.05932737	53
	2	42.38757627	-71.05928474	53
	3	42.38759985	-71.05921123	53
IC2-R	1-1	42.37886326	-71.04520781	48
	1-2	42.37880773	-71.04582919	48
	1-3	42.37847922	-71.04592080	48
	1-4	42.37859959	-71.04587561	48
IC2-R	2-1	42.37870945	-71.04601519	47
	2-2	42.37891048	-71.04592850	47
	2-3	42.37895787	-71.04602846	47
IC2-R	3-1	42.37924265	-71.04598514	47
	3-2	42.37917095	-71.04600058	48
	3-3	42.37908515	-71.04604613	48
	3-4	42.37923441	-71.04605380	48
IC2-R	4-1	42.37966881	-71.04584219	48
	4-2	42.37967674	-71.04588851	48
	4-3	42.37960392	-71.04591417	48

Appendix B-1 and B-2. List of Species Identified from the June 2000 Samples Taken from Four CAD Cells and Reference Stations for the BHNIP.

Appendix B-1. Species Identified in the June 2000 Samples

CNIDARIA
Hydrodea
- Campanularidae
  - Campanularia gigantea Hincks, 1865

ANNELIDA
Polychaeta
- Capitellidae
  - Capitella capitata *Eisig, 1887*
  - *Mediomastus ambiseta* Hartman, 1947
- Cirratulidae
  - *Tharyx acutus* Webster & Benedict, 1887
- Glyceridae
  - *Glycera americana* Leidy, 1855
- Hesionidae
  - *Microphthalmus sczelkowii* Mecanikow, 1865
- Nephtyidae
  - *Nephtys incisa* Malmgren, 1865
- Nereididae
  - *Nereis grayi* Pettibone, 1956
- Spionidae
  - *Polydora cornuta* Bosc, 1802
  - Spio thuleni Maciolek, 1990
  - *Streblospio benedicti* Webster, 1879
  - *Trochochaeta multisetosa* (Oersted, 1844)

Oligochaeta
- Tubificidae
  - ***Tubificoides apectinatus*** Brinkhurst**,** 1965
  - *Tubificoides sp. 2*

CRUSTACEA
Amphipoda
- Ampeliscidae
  - *Ampelisca abdita* Mills, 1864

Decapoda
- Crangonidae
  - *Crangon septemspinosa* (Say, 1818)

MOLLUSCA
Bivalvia
- Myacidae
  - *Mya arenaria* Linnaeus, 1758
- Mytilidae
  - *Mytilus edulis* Linnaeus, 1758
- Nuculidae
  - *Yoldia limatula* (Say, 1831)
- Tellinidae
  - *Tellina agilis* Stimpson, 1857

Gastropoda
- *Lacuna vincta* Montagu, 1803
- *Ilyanassa trivittata* (Say, 1822)

Appendix B-2. Taxa recorded at each of the stations sampled in June 2000.
*Taxa not included in diversity calculations.

	STAT_ID	IC2-B-1A	IC2-B-2A	IC2-BR-A	M2-4	M2-B-1A	M2-B-2A	M4-2A	M4-5A	M8-B-1A	M8-B-2A	**Individual species sum**
	STAT_ARRIV	06/2000	6/2000	6/2000	6/2000	6/2000	6/2000	6/2000	6/2000	6/2000	6/2000	
DESCRIPTION	SPEC_CODE			Bio. Ref.								
Cnidaria												
Campanularia gigantea*	3704010119				1 colony			1 colony	1 colony			0
Polychaeta												0
Nereis grayi	5001240409				1							1
Nephtys incisa	5001250115		1	3						1		5
Glycera americana	5001270104	1										1
Polydora cornuta	5001430448	5	20	70	9		1	26	3	6	9	149
Spio thulini	5001430709	1						3		2		6
Streblospio benedicti	5001431801	9	8	5	2			9	6	2	1	42
Trochochaeta multisetosa	5001450203			1						1	1	3
Micropthalmus sczelkowii	5001210201		13				1					14
Tharyx acutus	5001500305	3	21	4	1				1			30
Capitella capitata complex	5001600101	46	30	12	7	1	23	18	8	1	19	165
Mediomastus ambiseta	5001600401		7								1	8
Oligochaeta												0
Tubificoides apectinatus	5009020906	9	37	2			1	3	8	2	12	74
Tubificoides sp. 2	50090209SP02	20	4				1	3	7	1	2	38
Gastropoda												0
Lacuna vincta*	5103090305									2 dead		0
Ilyanassa trivittata*	5105080202									1 dead		0
Bivalvia												0
Yoldia limatula	5502040511		1									1
Mytilus edulis	5507010101				6	3	1	1	2			13
Tellina agilis	5515310205	1	1	1								3
Mya arenaria	5517010201		1									1
Amphipoda												0
Ampelisca abdita	6169020108			2								2
Decapoda												0
Crangon septemspinosa	6179220103	1										1
Total spp. at station sum		96	144	100	26	4	28	63	35	16	45	557

Appendix C. SPI Image analysis

Station ID	Penetration Depth			Comments	Boundary Roughness		Redox Potential Discontiuity (PRD) Depth (cm)			RPD Comments
	Minimum	Maximum	Mean		Type	Thickness (cm)	Min.	Max.	Mean	
EX-1-2	21.23	22.62	21.87	undredged area, SPI ref	physical	1.39	0.25	1.10	>0 to 0.75	0.70
EX-2-2	21.10	22.40	21.68	undredged area, SPI ref	physical	1.30	0.28	0.66	>0 to 0.75	0.42
EX-3-2	21.34	21.32	20.69	undredged area, SPI ref	physical	-0.02	0.37	0.66	>0 to 0.75	0.50
IC2-1-1-1	15.75	16.51	16.14		physical	0.76	0.41	1.84	0.76 to 1.50	1. 08
IC2-2-2-2	17.87	18.48	18.08		physical	0.61	0.35	1.45	>0 to 0.75	0.73
IC2-3-2-2	18.19	18.86	18.49		physical	0.67	0.19	0.76	>0 to 0.75	
IC2-4-2-2	17.78	18.67	18.12		physical	0.89	0.12	0.82	>0 to 0.75	0.500
IC2-5-2-2	17.37	17.84	17.59		biological	0.47	0.31	1.29	>0 to 0.75	0.64
IC2-6-2-2	17.65	18.32	17.89		physical	0.67	0.15	1.07	>0 to 0.75	0.67
IC2-7-4-2	17.62	18.73	18.14		physical	1.11	0.31	0.88	>0 to 0.75	0.47
IC2-8-2-2	15.47	16.58	15.93		physical	1.11	0.34	1.42	0.76 to 1.50	0.82
ICR-1-1-1	12.05	15.85	13.35	undredged area, cell ref	physical	3.80	0.28	1.26	>0 to 0.75	0.76
ICR-2-3-2	10.41	11.77	11.29	undredged area, cell ref	physical	1.36	1.39	3.10	2.26 to 3.00	2.44
ICR-3-3-2	12.43	13.32	12.51	undredged area, cell ref	physical	0.89	0.25	0.75	>0 to 0.75	0.53
ICR-4-3-2	13.92	14.62	14.18	undredged area, cell ref	physical	0.70	0.50	1.39	0.76 to 1.50	1.00
M2-1-5-2	12.65	13.6	13.02		physical	0.95	0.15	0.41	>0 to 0.75	0.24
M2-2-3-1	15.47	18.10	17.07		physical	2.63	0.00	0.00	0.00	No oxic surface
M2-3-4-2	14.43	15.94	14.77		physical	1.51	0.00	0.00	0.00	No oxic surface
M2-4-4-1	11.48	13.13	11.96		physical	1.65	0.00	0.00	0.00	No oxic surface
M2-5-1-2	13.25	13.92	13.68		physical	0.67	0.00	0.00	0.00	No oxic surface
M2-6-3-2	21.07	22.68	21.81		physical	1.61	0.12	0.75	>0 to 0.75	0.40
M2-7-2-2	15.34	17.02	16.18		physical	1.68	0.00	0.00	0.00	No oxic surface
M2-8-1-2	20.75	21.42	21.10		physical	0.67	0.00	0.00	0.00	No oxic surface
M2-R-1-1-1	14.55	15.88	15.12	undredged area, cell ref	physical	1.33	0.15	0.79	>0 to 0.75	0.40
M2-R-1-2-2	17.02	17.72	17.36	undredged area, cell ref	physical	0.70	0.09	0.88	>0 to 0.75	0.41
M2-R-1-3-2	17.49	18.70	18.07	undredged area, cell ref	physical	1.21	0.00	1.17	>0 to 0.75	0.53
M4-1-3-2	11.17	12.08	11.73		physical	0.91	0.15	0.56	>0 to 0.75	0.34
M4-2-2-2	12.65	13.25	12.81		physical	0.60	0.12	1.13	>0 to 0.75	0.46
M4-3-1-2	14.87	15.56	15.21		physical	0.69	0.06	0.56	>0 to 0.75	0.31
M4-4-1-2	11.26	11.55	11.39		physical	0.29	0.15	0.56	>0 to 0.75	0.33

Station ID	Penetration Depth			Comments	Boundary Roughness		Redox Potential Discontiuity (PRD) Depth (cm)			RPD Comments
	Minimum	Maximum	Mean		Type	Thickness (cm)	Min.	Max.	Mean	
M4-5-3-2	11.39	13.98	12.79		physical	2.59	0.25	1.61	>0 to 0.75	0.66
M4-6-4-2	10.25	8.54	9.12		physical	-1.71	0.09	0.50	>0 to 0.75	0.27
M4-7-5-2	15.31	16.07	15.51		physical	0.76	0.18	0.53	>0 to 0.75	0.32
M4-8-1-2	15.03	16.07	15.43		physical	1.04	0.12	0.75	>0 to 0.75	0.35
M4-R-3-2	18.57	19.39	18.86	undredged area, cell ref	physical	0.82	0.15	1.17	0.76 to 1.50	0.78
M4-S-3-2	17.24	18.35	17.71	undredged area, cell ref	physical	1.11	0.37	1.10	>0 to 0.75	0.61
M4-T-2-2	14.96	16.70	15.61	undredged area, cell ref	physical	1.74	0.37	0.85	>0 to 0.75	0.47
M8-1-1-1	13.29	15.50	14.53		1.00	2.21	0.12	0.91	>0 to 0.75	0.43
M8-2-2-2	14.49	16.80	15.44		physical	2.31	0.31	0.82	>0 to 0.75	0.56
M8-3-5-2	16.77	18.13	17.15		physical	1.36	0.18	0.20	>0 to 0.75	0.42
M8-4-3-2	10.69	11.42	10.94		physical	0.73	0.31	0.75	>0 to 0.75	0.55
M8-5-2-2	22.56	22.72	22.64		physical	0.16	0.34	0.91	>0 to 0.75	0.63
M8-6-2-1	17.08	18.25	17.53		physical	1.17	0.15	0.75	>0 to 0.75	0.38
M8-7-3-2	5.82	9.05	8.24		physical	3.23	0.23	1.32	0.76 to 1.50	0.80
M8-8-2-1	13.06	13.67	13.41		physical	0.61	0.37	1.26	>0 to 0.75	0.93

Station ID	Grain Size (phi)			Grain Size comments		
	Minimum	Maximum	Mode			
EX-1-2	>4 (<62 um)	4 to 3 (62 um to 125 um)	>4 (<62 um)	little amnts. v.f. sand at surface	Silt/clay	silt/clay clay at about 10cm
EX-2-2	>4 (<62 um)	4 to 3 (62 um to 125 um)	>4 (<62 um)	small amt. of v.f. sand at surface and to 8cm	Silt/clay	Silt/clay, clay at 10 cm
EX-3-2	>4 (<62 um)	4 to 3 (62 um to 125 um)	>4 (<62 um)	v.f. sand at surfance and to 8cm	Silt/clay with v.f. sand at surface	Silt/clay, clay depth indeterminant
IC2-1-1-1	>4 (<62 um)	4 to 3 (62 um to 125 um)	>4 (<62 um)	No Coarse sand visible by REMOTS		v.f.s. over silt/clay
IC2-2-2-2	>4 (<62 um)	4 to 3 (62 um to 125 um)	>4 (<62 um)	No coarse sand visible by REMOTS		v.f.s. over silt/clay
IC2-3-2-2	>4 (<62 um)	4 to 3 (62 um to 125 um)	>4 (<62 um)	No coarse sand visible by REMOTS		v.f.s. over silt/clay
IC2-4-2-2	>4 (<62 um)	>4 (<62 um)	>4 (<62 um)	organic mineral aggregates present		No sand at these substations silt/clay
IC2-5-2-2	>4 (<62 um)	>4 (<62 um)	>4 (<62 um)	No Sand at this replicate		silt/clay
IC2-6-2-2	>4 (<62 um)	>4 (<62 um)	>4 (<62 um)	No Sand		Silt/clay
IC2-7-4-2	>4 (<62 um)	4 to 3 (62 um to 125 um)	>4 (<62 um)	small sub surface pockets of sand		silt/clay
IC2-8-2-2	>4 (<62 um)	>4 (<62 um)	>4 (<62 um)	only tiny fraction of v.f. sand at surface		silt/clay
ICR-1-1-1	>4 (<62 um)	>4 (<62 um)	>4 (<62 um)	OMA	No sand, all silt	
ICR-2-3-2	>4 (<62 um)	>4 (<62 um)	>4 (<62 um)		all silt/clay with OMA	
ICR-3-3-2	>4 (<62 um)	>4 (<62 um)	>4 (<62 um)		all silt/clay with OMA and RDSI	
ICR-4-3-2	>4 (<62 um)	>4 (<62 um)	>4 (<62 um)		all silt/clay	
M2-1-5-2	>4 (<62 um)	4 to 3 (62 um to 125 um)	>4 (<62 um)	two rows of sand cap material, 7 cm and 12 cm	fine layer of sand at surface, not much	Silt/clay over and between cap material
M2-2-3-1	>4 (<62 um)	3 to 2 (125 um to 250 um)	>4 (<62 um)	very fine layer of cap material at 12 cm	Microbial mats at surface, all silt over clay	Silt over clay, clay starts at about 9cm
M2-3-4-2	>4 (<62 um)	>4 (<62 um)	>4 (<62 um)	slight amount of cap material 14 cm	Silt at surface 0-8cm	Silt/clay, clay starts at about 9 cm
M2-4-4-1	>4 (<62 um)	3 to 2 (125 um to 250 um)	>4 (<62 um)	layer of sand cap material at 11.5 cm	Silt below surface to 8 cm	Silt over clay, clay at 8 cm and below
M2-5-1-2	>4 (<62 um)	1 to 0 (500 um to 1 mm)	>4 (<62 um)	Very coarse cap material at 10 cm	Silt at surface to 8cm	Silt/clay, clay starts at 8cm
M2-6-3-2	>4 (<62 um)	1 to 0 (500 um to 1 mm)	>4 (<62 um)	Coarse sand cap at 12-14 cm	Silt with pockets of v.f. sand throughout	Silt/clay, clay at about 15 cm
M2-7-2-2	>4 (<62 um)	>4 (<62 um)	>4 (<62 um)	No sand cap material in view	Silt below surface to 10 cm	Clay below silt from 10 cm to 17 cm
M2-8-1-2	>4 (<62 um)	3 to 2 (125 um to 250 um)	>4 (<62 um)	some cap material dispersed at 18 cm	Silt at surface to 9 cm	Clay below surface 9cm to 21 cm
M2-R-1-1-1	>4 (<62 um)	4 to 3 (62 um to 125 um)	>4 (<62 um)	pocket of sand around 8 cm	RSDI present	some sand near surface, mostly silt/clay
M2-R-1-2-2	>4 (<62 um)	4 to 3 (62 um to 125 um)	>4 (<62 um)	V.F. sand distributed throughout		silt/clay
M2-R-1-3-2	>4 (<62 um)	>4 (<62 um)	4 to 3 (62 um to 125 um)	v.f. sand distributed throughout	Silt/clay	Silt/clay
M4-1-3-2	>4 (<62 um)	3 to 2 (125 um to 250 um)	>4 (<62 um)	minimal amounts of v.f.sand only at surface	Coarse sand cap material 8cm below surface	Silt/clay over coarse sand cap material
M4-2-2-2	>4 (<62 um)	1 to 0 (500 um to 1 mm)	>4 (<62 um)	Coarse cap sand material 13 cm below surface	2 cm v.f. sand at surface	Silt/clay above coarse sand cap
M4-3-1-2	>4 (<62 um)	1 to 0 (500 um to 1 mm)	>4 (<62 um)	Coarse cap material 12 cm below surface	v.f. sand at surface with silt	Silt/clay above cap material
M4-4-1-2	>4 (<62 um)	3 to 2 (125 um to 250 um)	>4 (<62 um)	coarse cap material not visiable	Silt at surface with 3 cm layer of sand below	Silt/clay at bottom, boundary void present
M4-5-3-2	>4 (<62 um)	3 to 2 (125 um to 250 um)	3 to 2 (125 um to 250 um)	mixed sand cap material throughout window	Silty clay below surface	Silt clay below defined layer of cap material
M4-6-4-2	>4 (<62 um)	3 to 2 (125 um to 250 um)	4 to 3 (62 um to 125 um)	boundary void at clay/sand cap layer	Silty clay just below surface	sand throughout with min. v.f. sand at surface

Station ID	Grain Size (phi)			Grain Size comments		
	Minimum	Maximum	Mode			
M4-7-5-2	>4 (<62 um)	4 to 3 (62 um to 125 um)	>4 (<62 um)	coarser cap sand throughout	1 cm v.f. sand at surface	silt/clay above bottom
M4-8-1-2	>4 (<62 um)	3 to 2 (125 um to 250 um)	>4 (<62 um)	coarse sand cap at 13 cm below surface	< 1cm sand at surface	Silt/clay above sand cap to surface
M4-R-3-2	>4 (<62 um)	>4 (<62 um)	>4 (<62 um)		all silt/clay	
M4-S-3-2	>4 (<62 um)	>4 (<62 um)	>4 (<62 um)		all silt/clay	
M4-T-2-2	>4 (<62 um)	>4 (<62 um)	>4 (<62 um)		all silt/clay	
M8-1-1-1	>4 (<62 um)	4 to 3 (62 um to 125 um)	>4 (<62 um)	v.f. sand just at surface	silt	silt
M8-2-2-2	>4 (<62 um)	4 to 3 (62 um to 125 um)	>4 (<62 um)	v.f. sand just at surface	Silt	Silt
M8-3-5-2	>4 (<62 um)	4 to 3 (62 um to 125 um)	>4 (<62 um)	silt with v.f. sand at surface	silt	silt
M8-4-3-2	>4 (<62 um)	4 to 3 (62 um to 125 um)	>4 (<62 um)	small amts. v.f. sand at surface	silt	silt
M8-5-2-2	>4 (<62 um)	3 to 2 (125 um to 250 um)	>4 (<62 um)	sandy muds surface to 16 cm	silt	silt below sandy surface
M8-6-2-1	>4 (<62 um)	3 to 2 (125 um to 250 um)	>4 (<62 um)	V.F. sand at surface, sand pocket at rt. side	silt at surface	Silt to bottom, no clay, also RDSI
M8-7-3-2	>4 (<62 um)	3 to 2 (125 um to 250 um)	>4 (<62 um)	Chaotic fabric, sand suface to 3cm and throughout	sand and silt at surface	silt below surface with dewatering pipe
M8-8-2-1	>4 (<62 um)	3 to 2 (125 um to 250 um)	>4 (<62 um)	Chaotic fabric, some sand mixed in with silt	silt and f. sand at surface	silt with some clay

Station ID	Burrow	Burrow Comments	Infauna	Infauna Comments	Epifauna	succ stg	succ stg Comments
EX-1-2	no		yes	tiny polychaete tubes at surface	no	stage I	tiny polychaete tubes at surface
EX-2-2	yes	polychaete burrows at surface	yes	polychaete tubes at surface	no	stage I	polychaete tubes at surface and burrows
EX-3-2	no		yes	Polychaete tubes at surface	no	stage I	polychaete tubes at surface
IC2-1-1-1	yes	14 cm feeding void	yes	Polychaete tubes	no	stage I	worm tubes
IC2-2-2-2	yes		yes	burrowing polychaete worm	no	stage I	polychaete worm present in burrow
IC2-3-2-2	no		yes	burrowing polychaete worm visibe 13.4 cm	no	stage I	
IC2-4-2-2	yes	two relic feeding voids at 7.49 cm and 9.02 cm	yes	polychaete tubes at surface	no	stage I	polychaete tubes at surface
IC2-5-2-2	yes	feeding void at 8cm	yes	polychaete at 4 cm and tubes at surface	no	stage I	polychaete at 4.5 cm
IC2-6-2-2	yes	feeding void at 14.5 cm	yes	polychaete tubes at surface	no	stage I	small polychaete tubes at surface
IC2-7-4-2	yes	two polychaetes burrowed at 7.5 cm	yes	polychaete worms at 7.5 cm	no	stage I	two polycheates burrowed at 7.5 cm
IC2-8-2-2	no		yes	polychaete worm tubes at surface	no	stage I	polychaetes at surface
ICR-1-1-1	yes	burrow at 4cm	yes	tubes and burrows at surface	no	stage I	polychaete burrows and tubes
ICR-2-3-2	yes	mixing sediments	yes	worm tubes and burrows at surface	yes	stage I-II	Possible amphipod tubes
ICR-3-3-2	yes	U shaped burrow at 5cm, maybe stage III	yes	burrows and polychaete tubes at surface	no	stage I	U shaped feeding burrow
ICR-4-3-2	yes	large feeding void at 11 cm	yes	burrows and worm tubes at surface	no	stage I	worm tubes at surface
M2-1-5-2	no		yes	polychaete tubes	no	stage I	very small polychaete tubes present
M2-2-3-1	no		no		yes	Azoic	microbial mats at surface
M2-3-4-2	no		yes	tiny polychaete tubes at surface	yes	stage I	tiny polychaete tubes in microb. mat at surface
M2-4-4-1	no		no		no	Azoic	No tubes present
M2-5-1-2	no		yes	one orange polychaete burrowing	no	stage I	one polychaete burrowing near surface
M2-6-3-2	no		yes	small polychaete burrowed near surface	no	stage I	small polychaete burrowed near surface
M2-7-2-2	no		no		yes	Azoic	No polychaetes present, microb. Mats pres
M2-8-1-2	no		yes	tiny polychaete tubes at surface	yes	stage I	tiny polychaete tubes, microb. Mats present
M2-R-1-1-1	yes	evidence of subsurface burrows	yes	small worm tubes at surface	no	stage I	worms at surface, evid. of burrowing
M2-R-1-2-2	yes	relic void at 13 cm	yes	evidence of burrowing	no	stage I	evidence of burrowing
M2-R-1-3-2	yes	large burrow or dewater at surface	yes	evidence of sediment reworking	no	stage I	evidence of sediment reworking
M4-1-3-2	yes	polychaete at 5cm	yes	polychaete (Capitella?) at 5cm	no	stage I	polychaete burrowing at 5cm
M4-2-2-2	no		yes	polychaete tubes at surface	no	stage I	polychaete tubes at surface
M4-3-1-2	no		yes	tiny worm tubes at surface	no	stage I	tiny worm tubes at surface
M4-4-1-2	no		no		no	stage I	sediment reworked, maybe tiny polychaete tubes
M4-5-3-2	no		no		no	stage I	evidence of sediment reworking
M4-6-4-2	no		no		no	stage I	sediment reworking present

Station ID	Burrow	Burrow Comments	Infauna	Infauna Comments	Epifauna	succ stg	succ stg Comments
M4-7-5-2	yes	polychaetes at surface	yes	polychaete tubes at surface	no	stage I	polychaete burrows and tubes present
M4-8-1-2	no		yes	worm tubes at surface	no	stage I	tiny worm tubes at surface
M4-R-3-2	no	maybe relic feeding voids	yes	worm tubes at surface	no	stage I	worm tubes at surface
M4-S-3-2	yes	relic feeding void at 7cm	yes	Worm tubes at surface	no	stage I	worm tubes at surface
M4-T-2-2	no		yes	worm tubes at surface	no	stage I	worm tubes at surface
M8-1-1-1	yes	polychaet burrows	yes	polychaete tubes at surface, evidence of burrows	yes	stage I-II	possible amphipod tubes at surface
M8-2-2-2	no		yes	Polychaetes	yes	stage I	polychaetes, tubes present, dewatering pipe
M8-3-5-2	yes	polychaete burrows	yes	polychaetes, burrrows and tubes present	yes	stage I-II	polychaets and possible amphipod tubes
M8-4-3-2	yes		yes	polychaete worms	no	stage I	Worm tubes at surface and burrows
M8-5-2-2	yes	polychaete at 5cm and at surface	yes	polychaete tubes at surface	no	stage I	worm tubes and burrows
M8-6-2-1	yes	burrows at surface and RDSI	yes	Worms at surface	no	stage I	tubes and polychaete worms
M8-7-3-2	yes		yes	worms and tubes, dewatering pipe	yes	stage I-II	polychaetes and poss. amphipods at surf.
M8-8-2-1	yes	polychaete at 4cm	yes	worms at surface, dewatering pipe	no	stage I	worms burrowed with dewatering pipe

Station ID	Anoxia	Clast	Clast Comments	Methane	Methane Comments	OSI	Boudary Roughness	Boundary Roughness Calc.
EX-1-2	no	yes		no	sediment reworking by polychaetes	2	physical	1.39
EX-2-2	no	no		no		2	physical	1.3
EX-3-2	no	no		no		2	physical	-0.02
IC2-1-1-1	no	no		no		3	physical	0.76
IC2-2-2-2	no	no		no		2	physical	0.61
IC2-3-2-2	no	no		no		2	physical	0.67
IC2-4-2-2	no	no		no	.	2	physical	0.89
IC2-5-2-2	no	no		no		2	biological	0.47
IC2-6-2-2	no	no		no		2	physical	0.67
IC2-7-4-2	no	no		no		2	physical	1.11
IC2-8-2-2	no	no		no		3	physical	1.11
ICR-1-1-1	no	no		no		2	physical	3.8
ICR-2-3-2	no	no		no		6	physical	1.36
ICR-3-3-2	no	no		no		2	physical	0.89
ICR-4-3-2	no	yes	white clay clasts	no		3	physical	0.7
M2-1-5-2	no	no		no		2	physical	0.95
M2-2-3-1	yes	no		yes	present 3-5 cm, 8 bubbles 0.25-0.75 cm	-10	physical	2.63
M2-3-4-2	yes	no		no	no methane in this image	-3	physical	1.51
M2-4-4-1	yes	no		no	no methane present	-8	physical	1.65
M2-5-1-2	yes	yes	small white clay clasts at 8cm	no		-3	physical	0.67
M2-6-3-2	no	no		no		2	physical	1.61
M2-7-2-2	yes	no		yes	Gas bubbles at 3-4 cm, 6 bubbles 0.5-1 cm	-10	physical	1.68
M2-8-1-2	yes	yes	white clay clasts at 13 cm	yes	7 gas bubbles, 0.5-1.0cm at 3cm	-5	physical	0.67
M2-R-1-1-1	no	no		no		2	physical	1.33
M2-R-1-2-2	no	no		no			physical	0.7
M2-R-1-3-2	no	no		no			physical	1.21
M4-1-3-2	no	no		no		2	physical	0.91
M4-2-2-2	no	no		yes	methane around cap material as large bubble	0	physical	0.6
M4-3-1-2	no	no		no		2	physical	0.69
M4-4-1-2	no	no		no		2	physical	0.29
M4-5-3-2	no	no		no	Iron oxide present at surface	2	physical	2.59
M4-6-4-2	no	yes	white clasts, could be clay	no		2	physical	-1.71

Station ID	Anoxia	Clast	Clast Comments	Methane	Methane Comments	OSI	Boudary Roughness	Boundary Roughness Calc.
M4-7-5-2	no	no		yes	tiny bubbles at 9 cm, 0.10-0.50 cm	0	physical	0.76
M4-8-1-2	no	yes	White clay clast at 7cm	no		2	physical	1.04
M4-R-3-2	no	no		yes	a large 2.5 cm bubble at 11 cm	1	physical	0.82
M4-S-3-2	no	no		no		2	physical	1.11
M4-T-2-2	no	yes	white clay clasts	no			physical	1.74
M8-1-1-1	no	no	Organic mineral aggregates present	no		3	1	2.21
M8-2-2-2	no	no	Organic mineral aggregates present	no		2	physical	2.31
M8-3-5-2	no	yes	white clay clasts throughout slide	no		3	physical	1.36
M8-4-3-2	no	no		no		2	physical	0.73
M8-5-2-2	no	no		no		2	physical	0.16
M8-6-2-1	no	no		no		2	physical	1.17
M8-7-3-2	no	no		no		4	physical	3.23
M8-8-2-1	no	no		no		2	physical	0.61